High Energy X-Ray Scattering for Engineering Applications Breakout Session III

Presenter M. Croft (Rutgers)

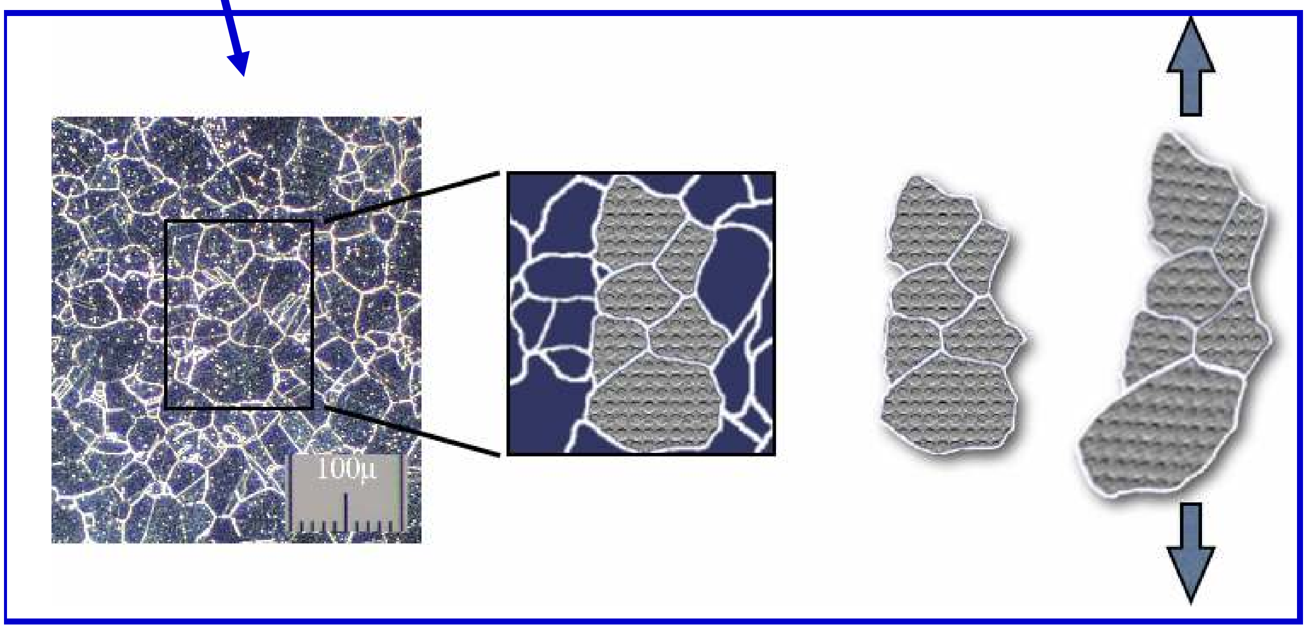
Session Discussions fell in two categories

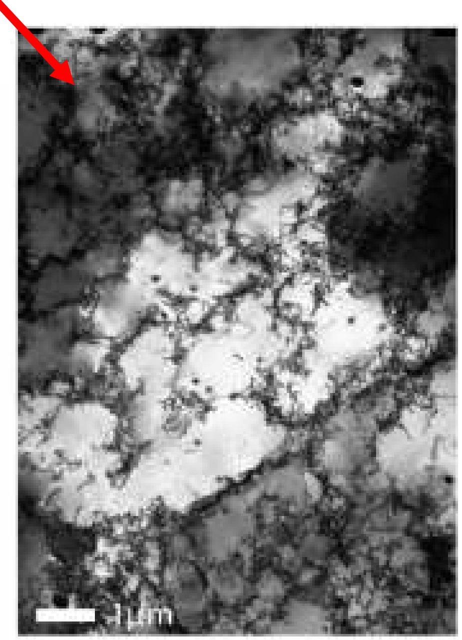
A.] Grain size-scale up (bottom-up) understanding of mechanical properties, as probed by monochromatic beam ~ 80 keV diffraction. For this group the powder diffraction insertion device would be useful in its present form, with additional facilities.

B.] The greatest part of the discussion focused on the unanimous recognition of the need for materials/engineering diffraction facility for crystal-phase and strain field mapping. This 30-200 keV diffraction facility (dominantly white beam) requires a multi-pole superconducting wiggler insertion device.

A.1 Micromechanical Behavior of Metallic Alloys

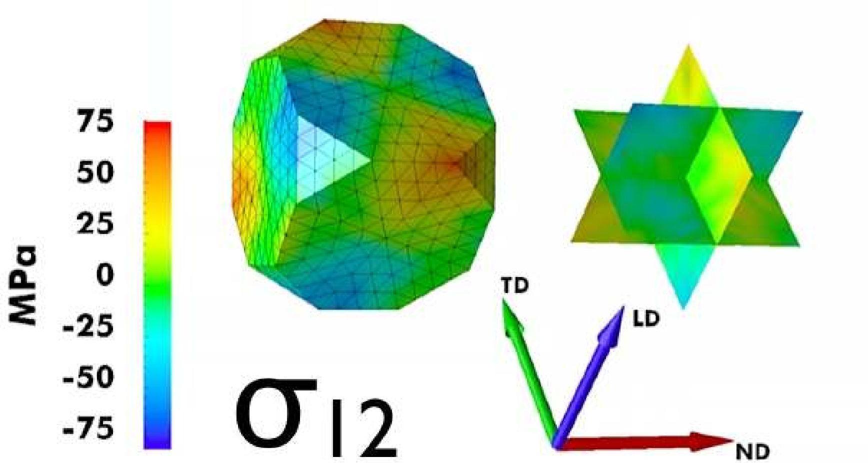
1. Real answers come from blend of models and tests.
2. Metallic crystals deform according to their orientation and neighborhood - micromechanically multiaxial.
3. Crystals subdivide during deformation.
4. Building realistic model specimens requires 3D structural information.

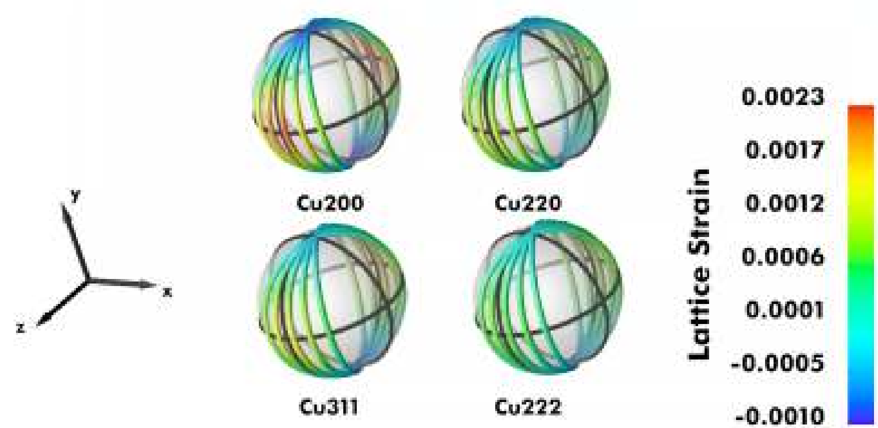




A.2 Strain Pole Figures and Stress Distributions

- Powder diffraction
- Diffractometer
- Fatigue-rated load frame
- Measure strain pole figures
- Calculate stress



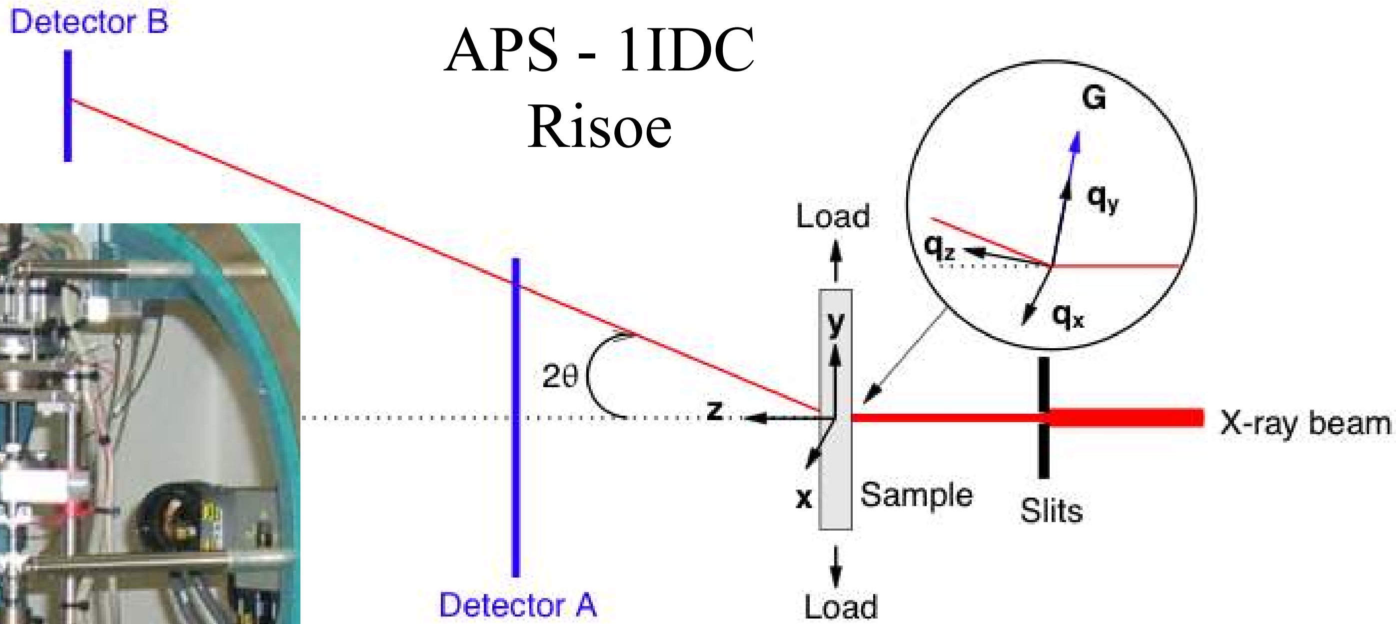


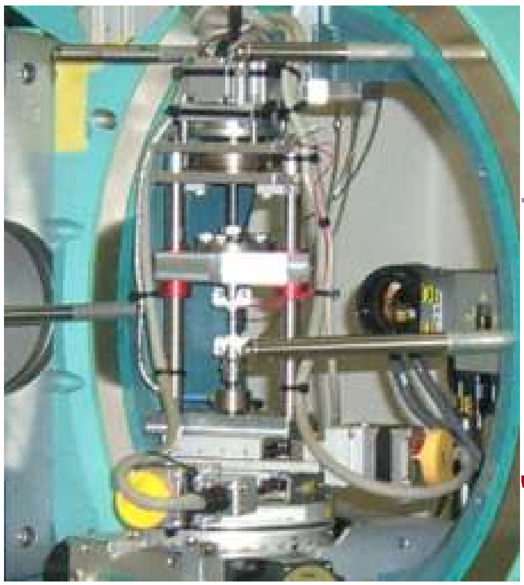
180 MPa

Single Grain, Single Spot Experiments - 3DXRD

A.3

APS - 1IDC
Risoe





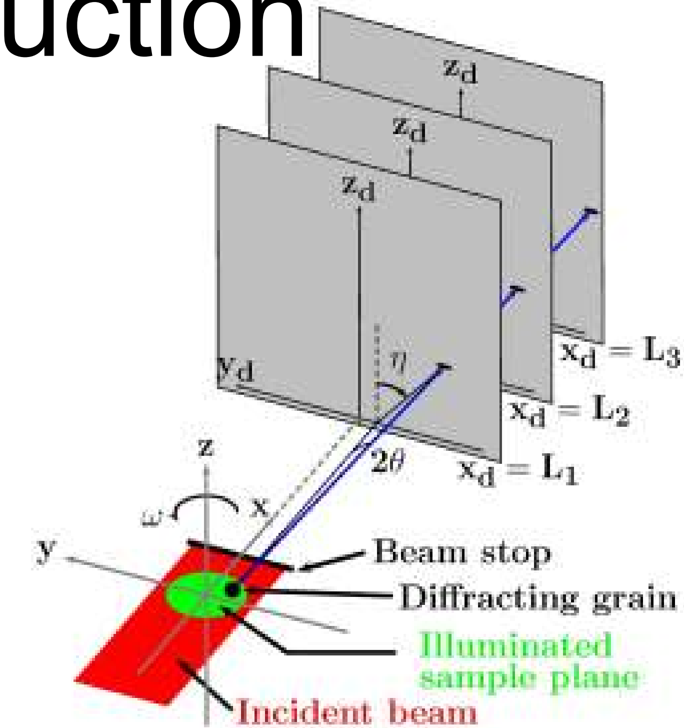
"pocket size" load frame

- Energy > 50 keV, beamsize - 10’s of grains
- Detector A ~ .7m, rings - Single grain stress
- Detector B ~ 8m, single spots - grain subdivision

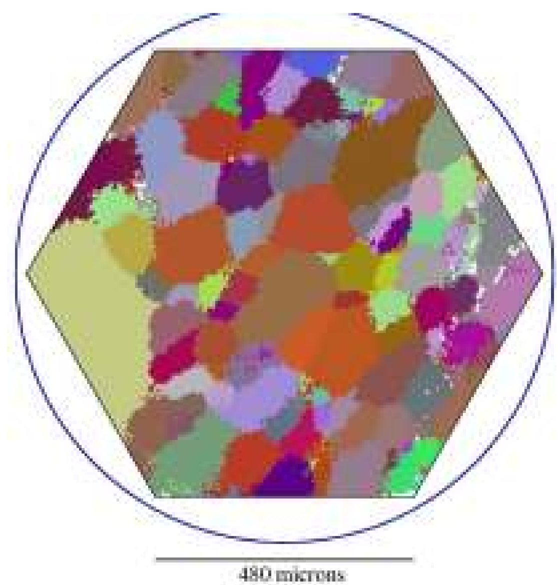
A.4

Grain Reconstruction

- Diffraction-based grain “tomography”
- Non-destructive reconstructive method
- Forward projection - Bob Suter CMU



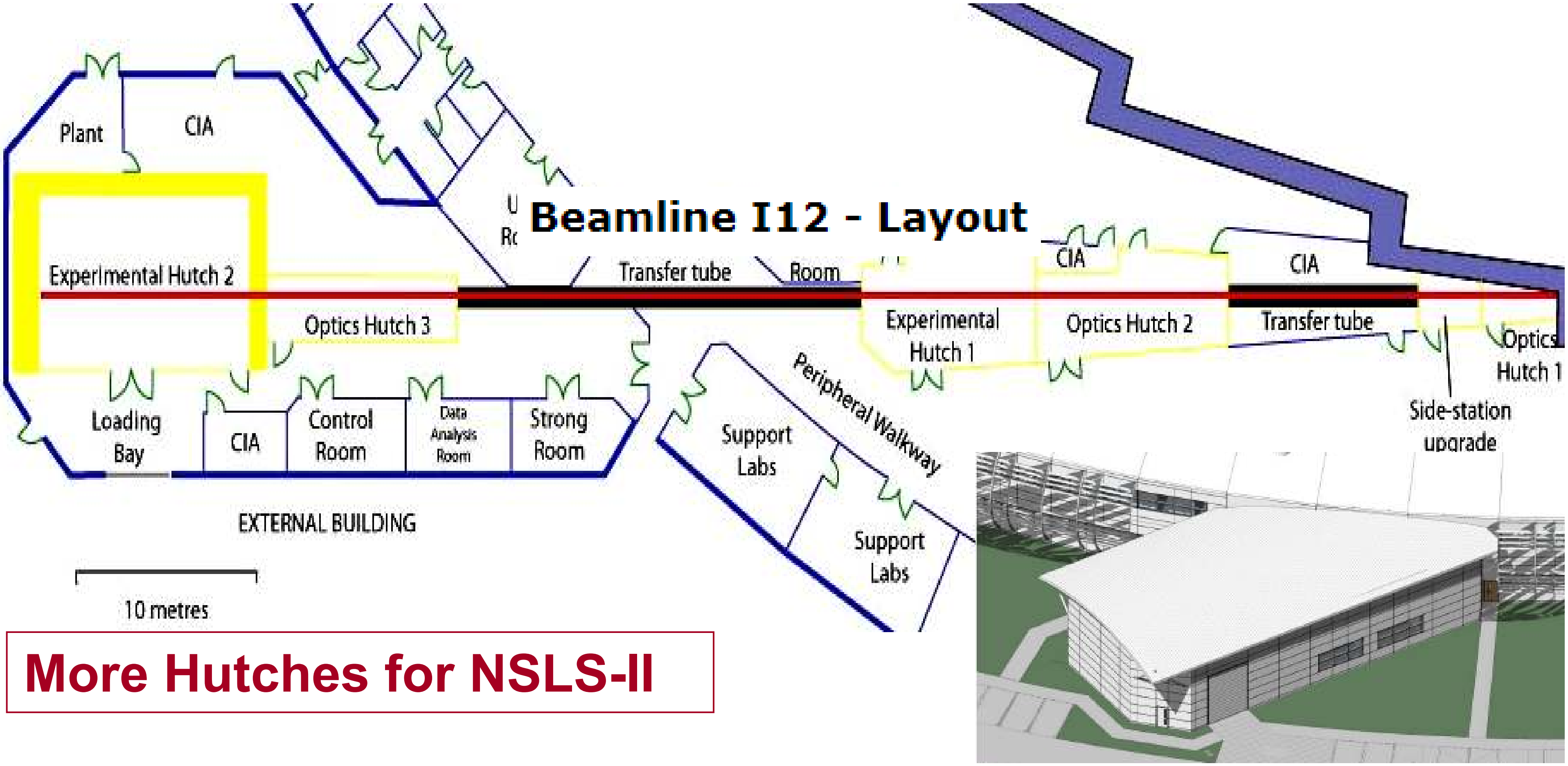
APS -1IDC



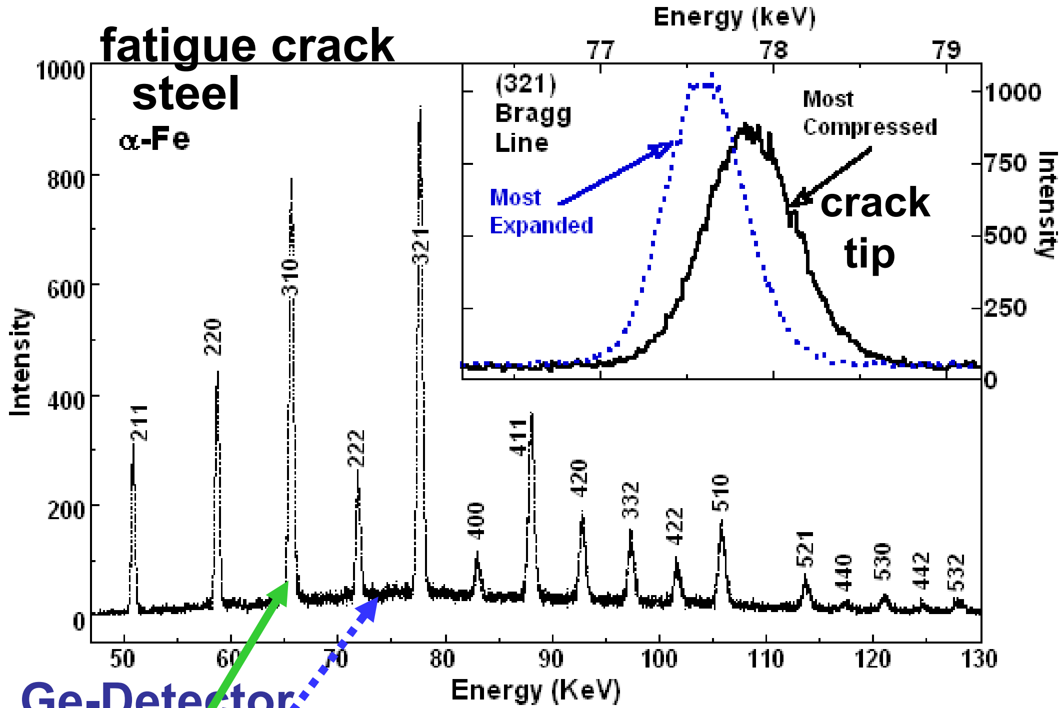
- White beam energy dispersive (EDXRD) + monochromatic x-ray diffraction
- 30-200 keV range, multi-pole superconducting wiggler.
- crystal-phase and strain field mapping

B.1

Diamond JEEP Materials & Processing facility prototype.



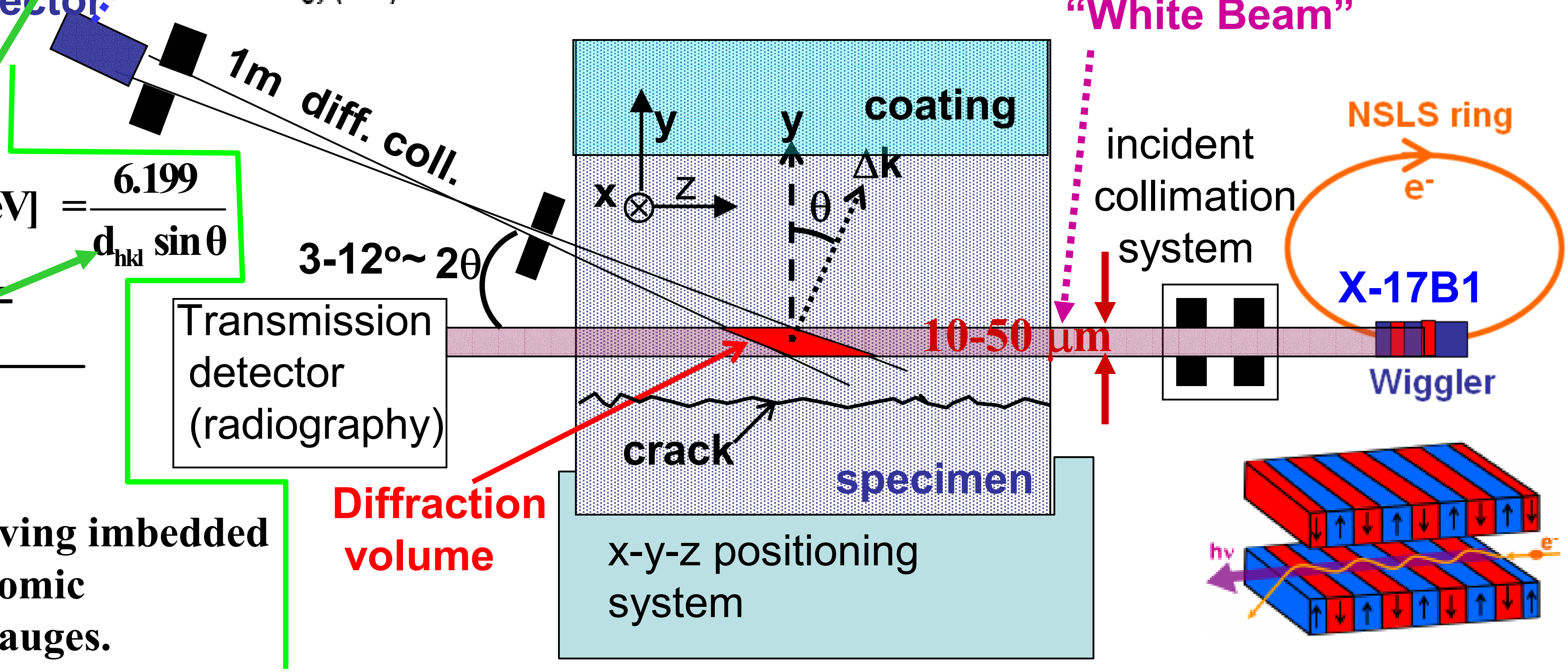
More Hutches for NSLS-II



Energy Dispersive Diffraction

- Fingerprint of structures phase evolution/mapping
- Precision lattice parameter shifts

B.2



$$E_{hkl}\ [\text{in keV}] = \frac{6.199}{d_{hkl}\sin\theta}$$

ε =

strain

Like having imbedded inter-atomic strain gauges.

Chemical Kinetics

(crystal structures vs time)

THINK BATTERIES

Hardening of cement

-hydration reaction

-followed by Si-O polymerisation

lots of heat given out early

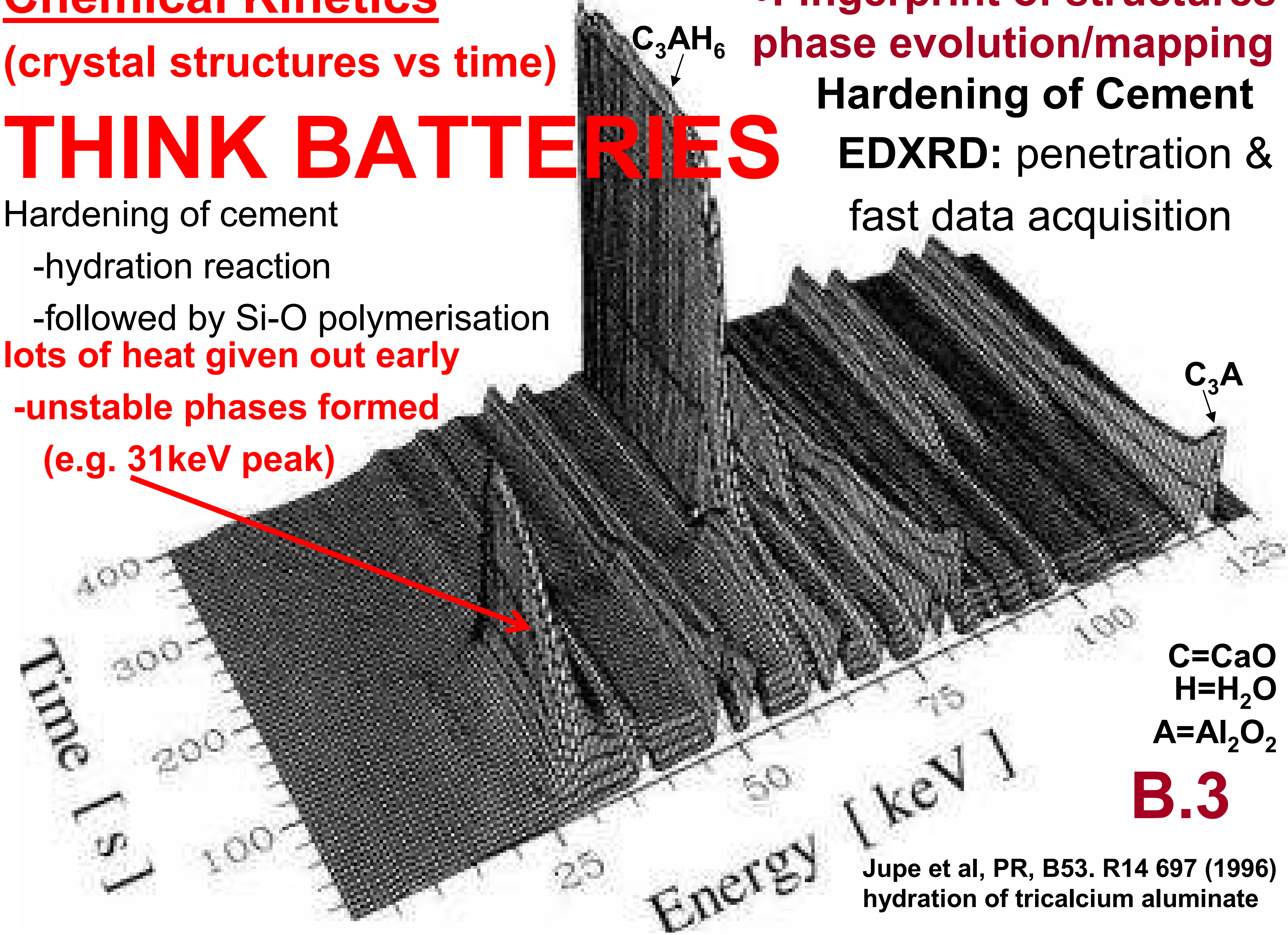
-unstable phases formed

(e.g. 31keV peak)

•Fingerprint of structures phase evolution/mapping

Hardening of Cement

EDXRD: penetration & fast data acquisition



C=CaO

H=H_2O

A=Al_2O_2

B.3

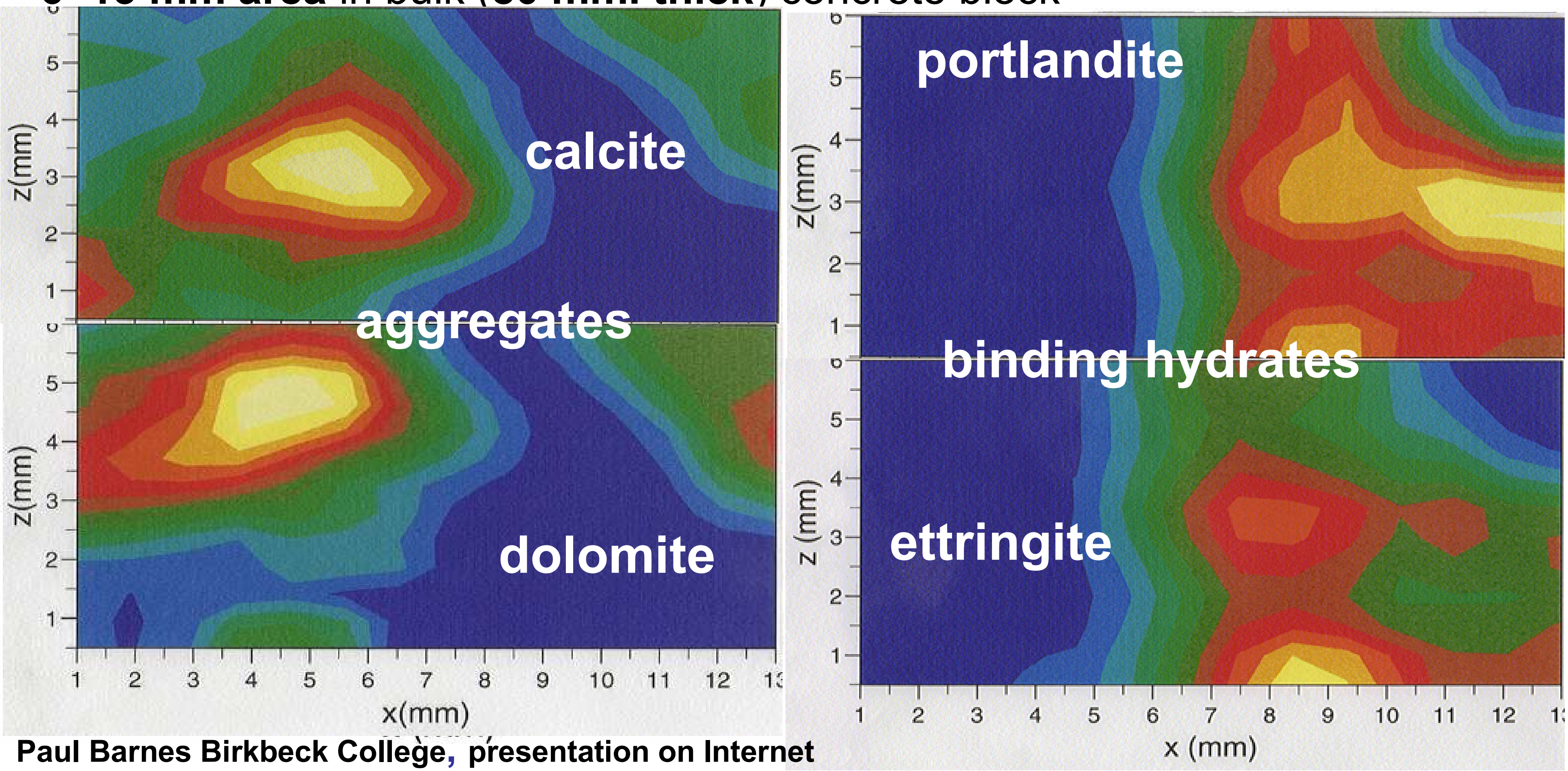
Jupe et al, PR, B53. R14 697 (1996)
hydration of tricalcium aluminate

Chemical Spatial Distribution (crystal structures vs position map)

THINK OPERATING BATTERIES & FUEL CELLS…

Tomographic Energy-Dispersive Diffraction Imaging (**TEDDI**)

6×13 mm area in bulk (**80 mm. thick**) concrete block



Paul Barnes Birkbeck College, presentation on Internet

(Adv. of *TEDDI* for studies of mat. chem. proc.and env. syst.)

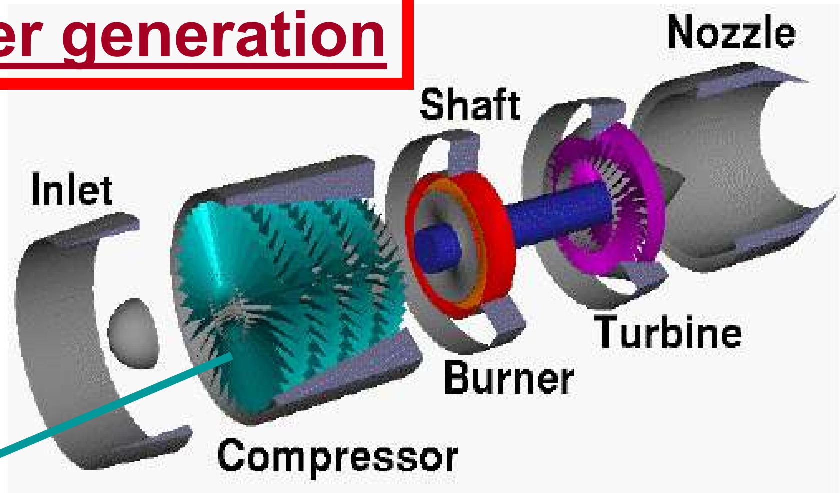
Hall et al, Cemment & Conc. Res. 30,492 (2000)

Future: Map crystal structures vs. position, time, temperature, voltage/current (batteries-fuel cells)… and their combinations

B.4

Aerospace/energy: Turbojet Engine

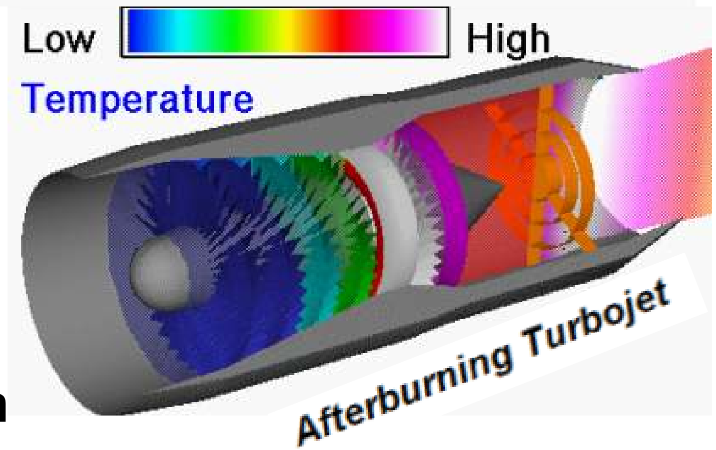
– prolusion and electric peak power generation



Hostile environment

– high strength (low weight)
– high temperatures
– high part $
– high cost of failure
– advanced materials

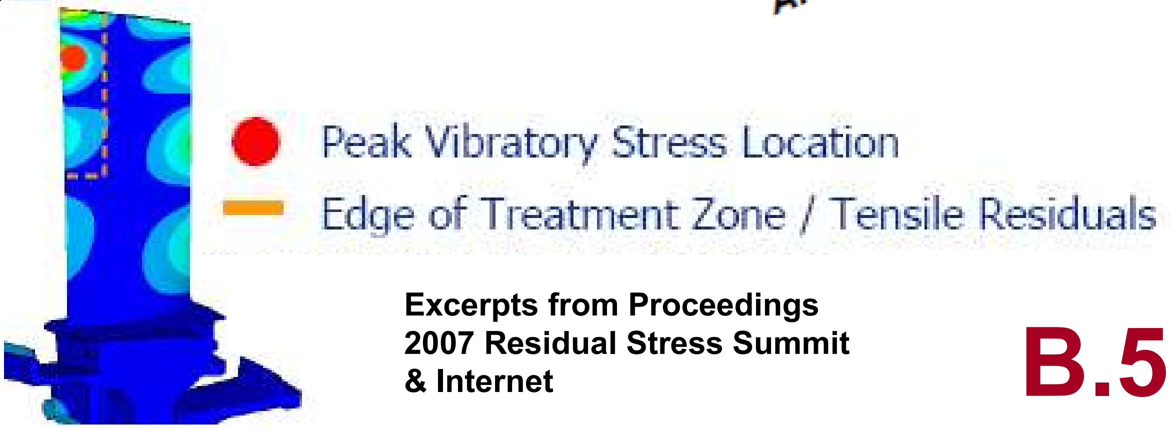
Compressor blades and mounting



Ti-6-4 alloy

Engineered Compressive Stresses

- fatigue life extension (nX)
- foreign object impact (FOI) damage reduction

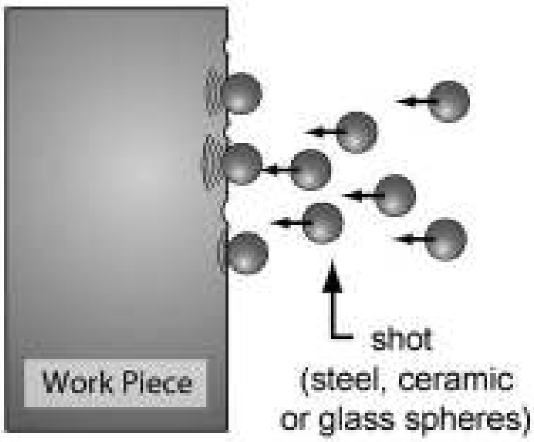


Excerpts from Proceedings
2007 Residual Stress Summit
& Internet

B.5

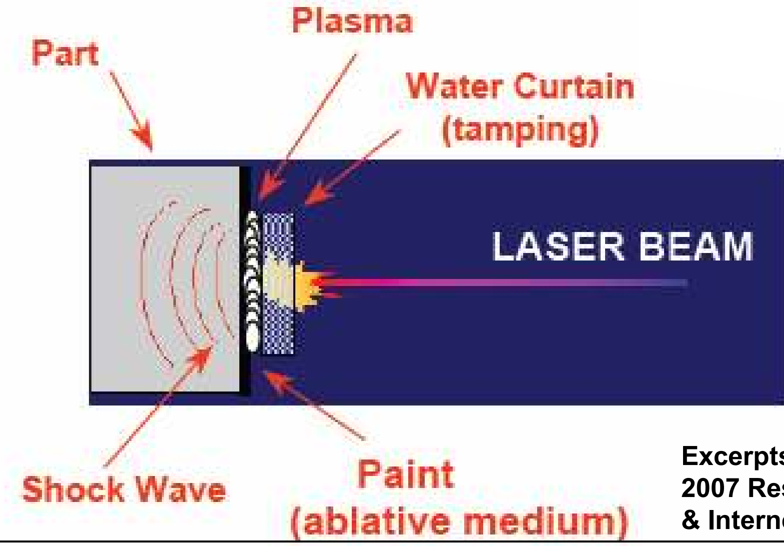
Selected examples of compressive stress engineering

Shot Peening



Used extensively in Ti-6-4 engine component processing

Laser Peening (Shock Peening)



B.6

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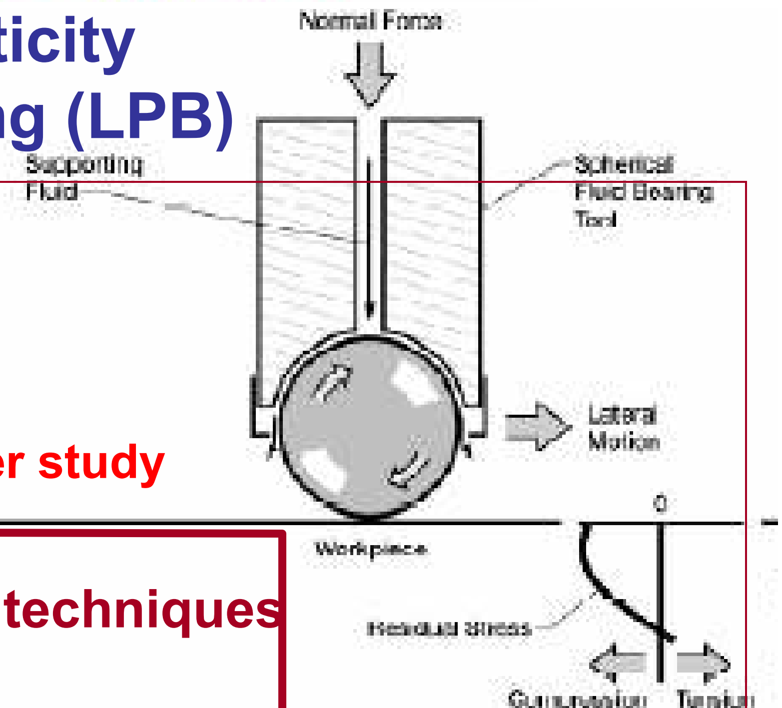
Low Plasticity Burnishing (LPB)



Under study

Application: X-ray profiling of stresses

- Depth & magnitude of compression
- relaxation under temperature/load
- validation of

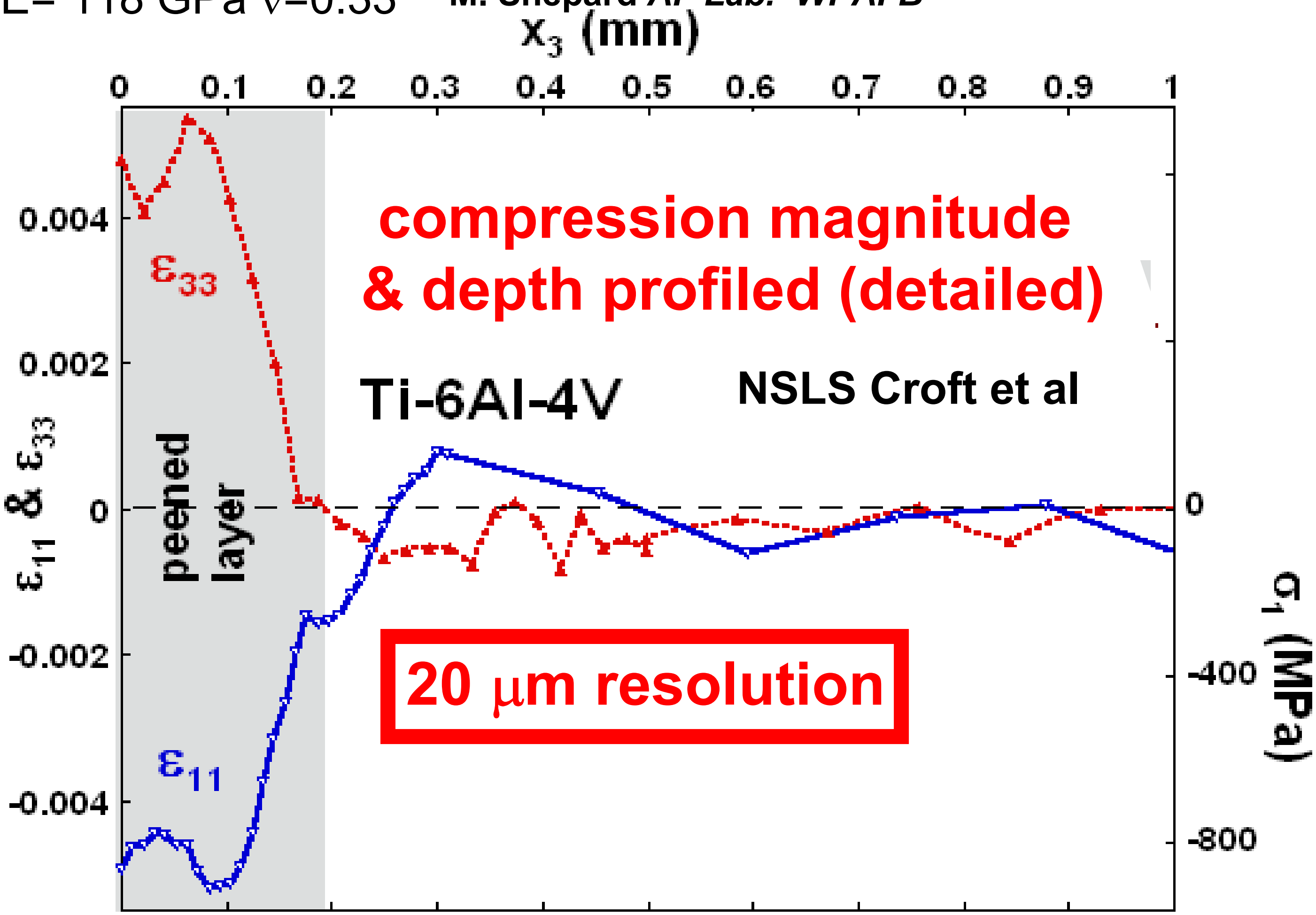
  finite element calculations

  destructive residual stress measurement techniques

Ti-6-4 alloy aerospace specimen

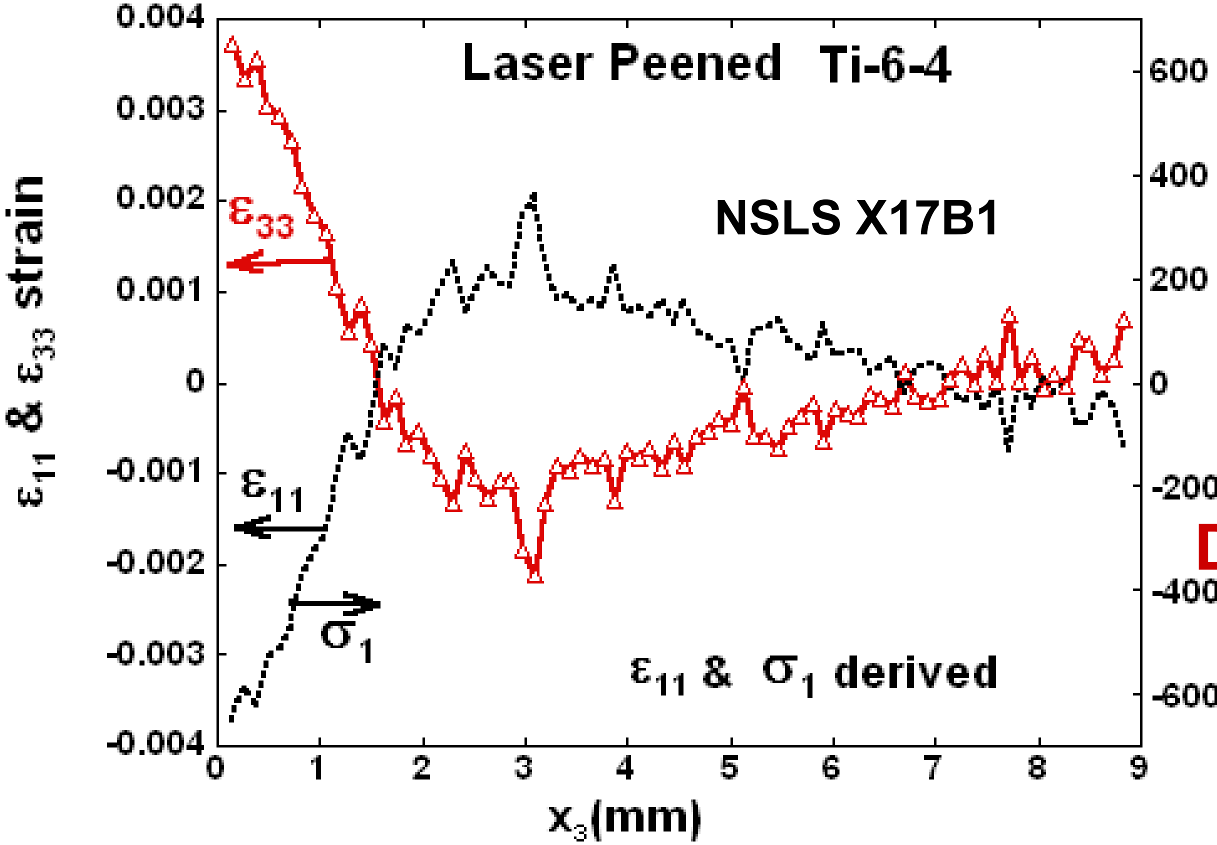
Shot peened surfaces

E= 118 GPa ν=0.33 M. Shepard *AF Lab. WPAFB*

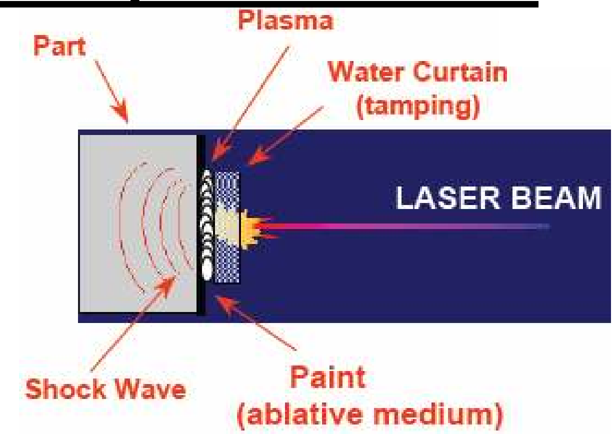


Can now study relaxation fatigue, T(C°)+ stress+…

B.7



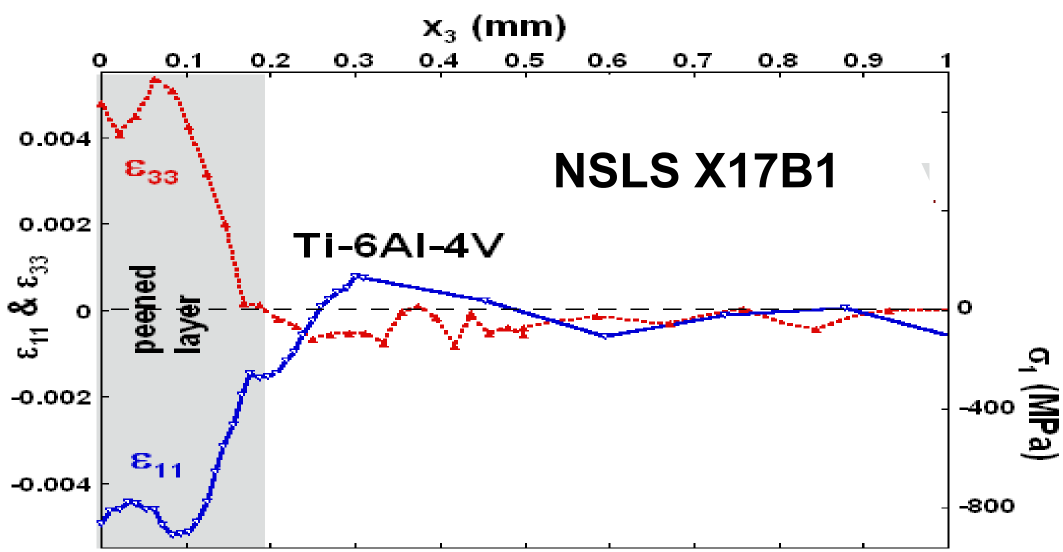
Laser peened Ti-6-4



DEEP COMPRESSION !

Example*

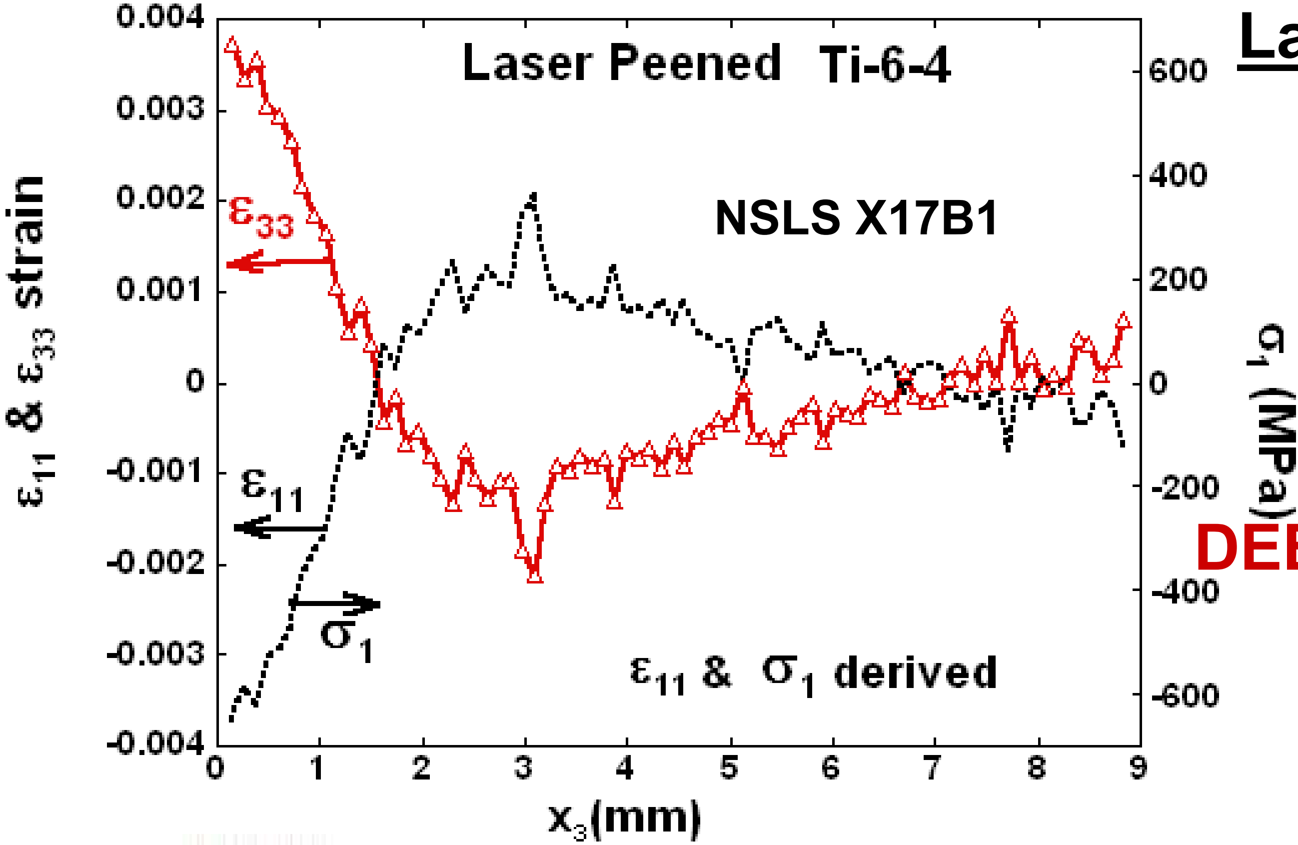
(*Representative of x-ray capabilities only not of optimized processing technique.)



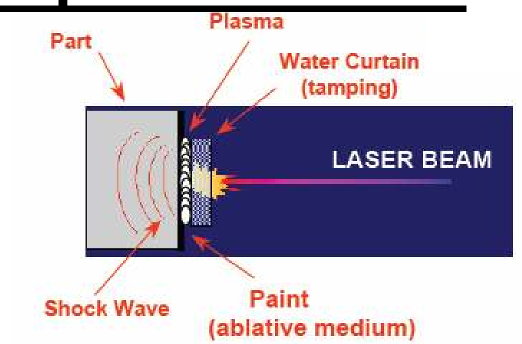
Compare shot peened Ti-6-4

B.8

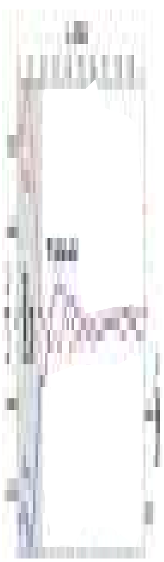
Excerpts from Proceedings 2007 Residual Stress Summit & Internet



Laser peened Ti-6-4



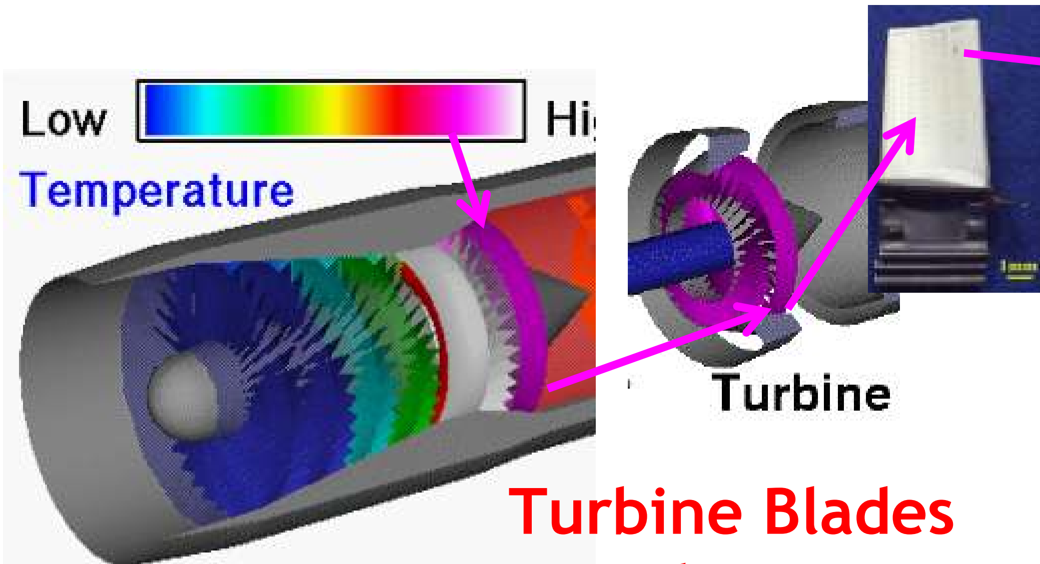
DEEP COMPRESSION !

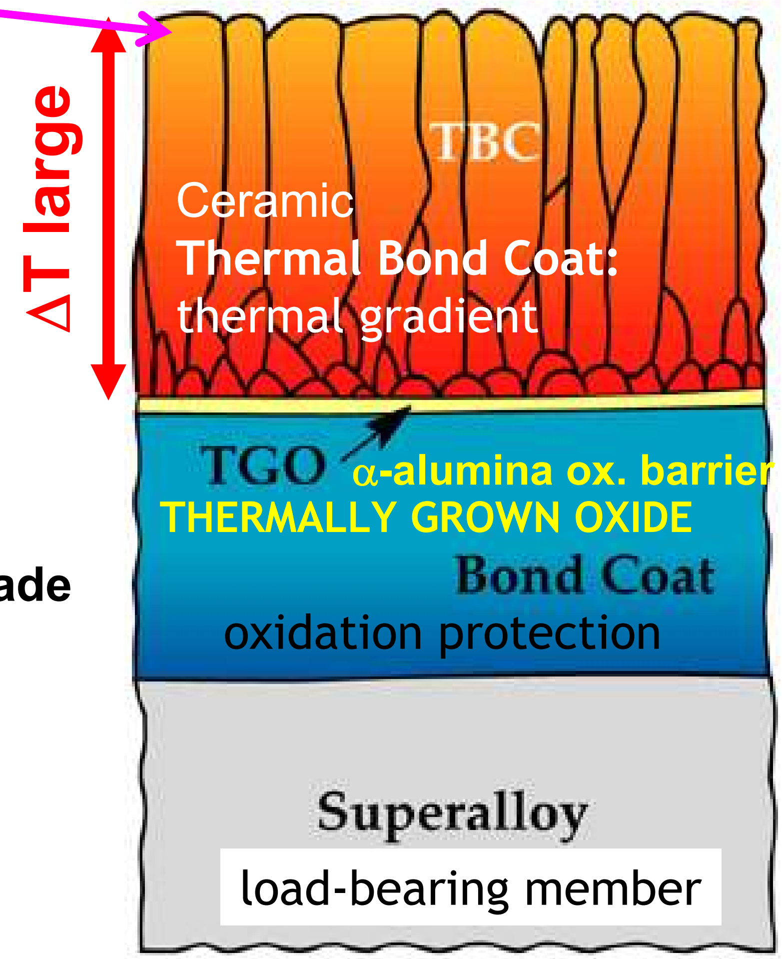


Compare
shot peened Ti-6-4

DEEP COMPRESSION !

B.9





Turbine Blades and Vanes

Understanding/advancing complex turbine blade structures (residual stresses)

TBC compressive stress
-accumulated damage- relaxation
-dramatic mean stress drop
- ΔT currently limited

At issue: Loss of the engine part, engine, or a class A mishap.

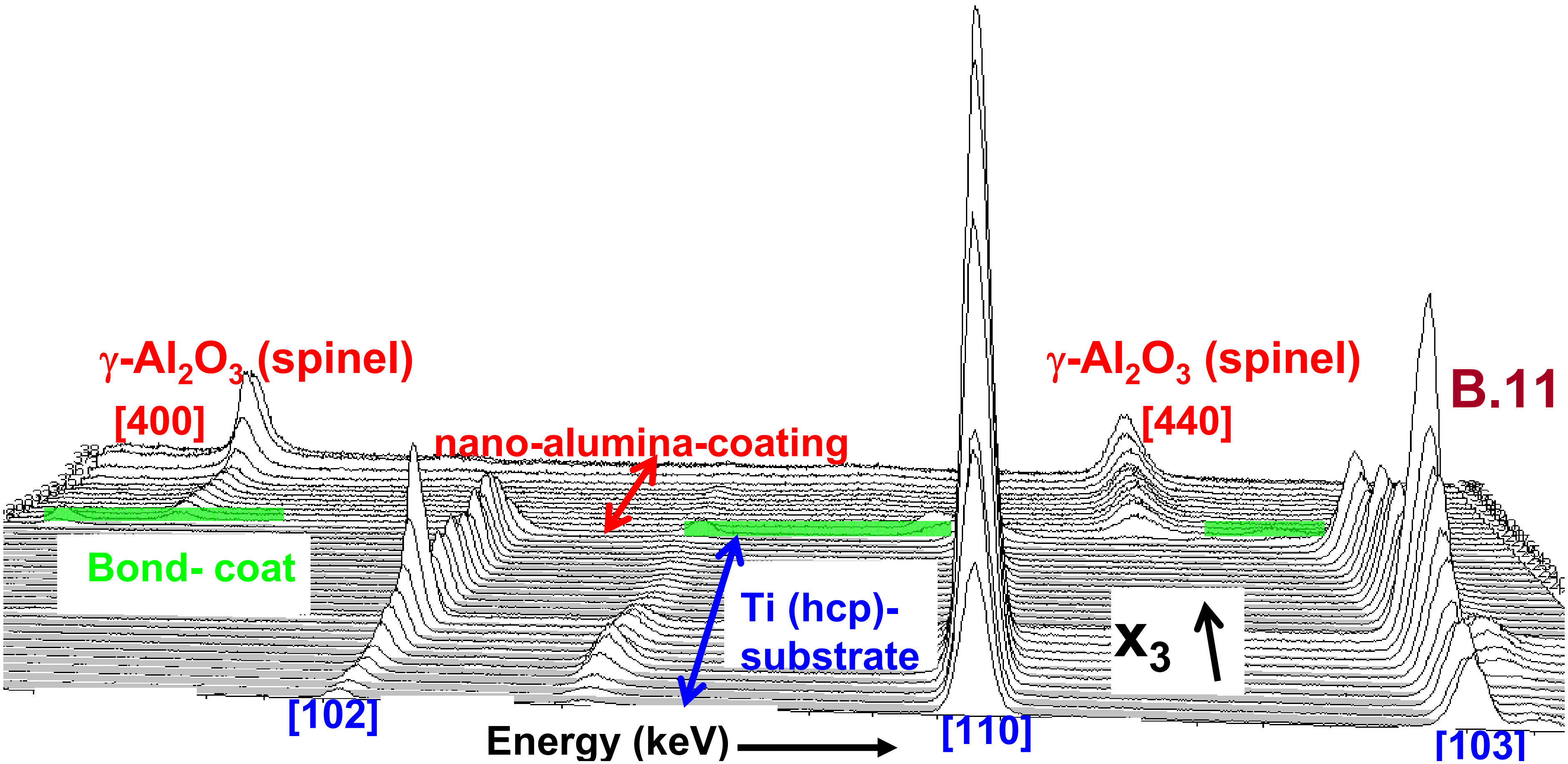
B.10

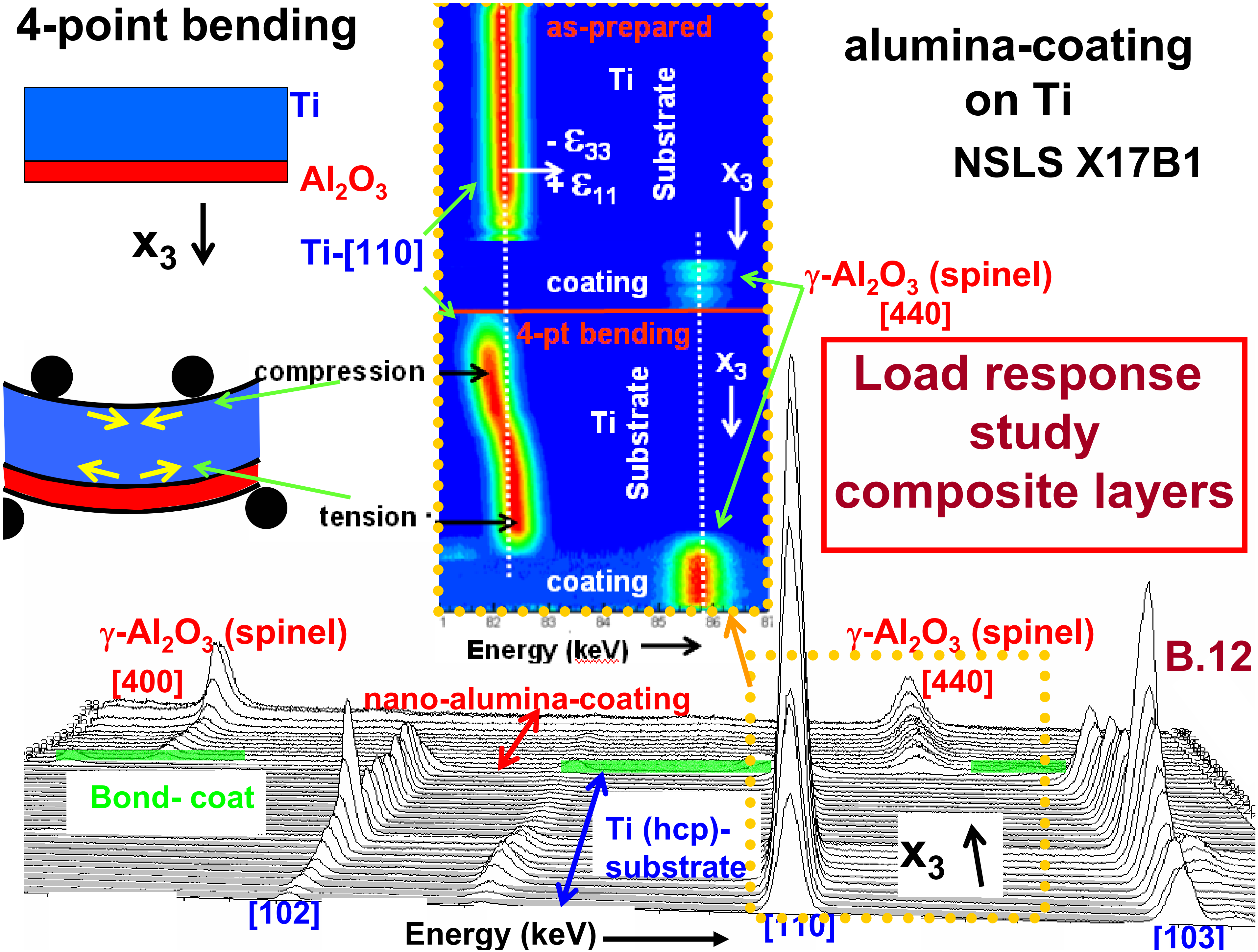
Excerpts from Proceedings 2007 Residual Stress Summit & Internet

Application: X-ray profiling of stresses & relaxation in complex structure.
modes of failure…

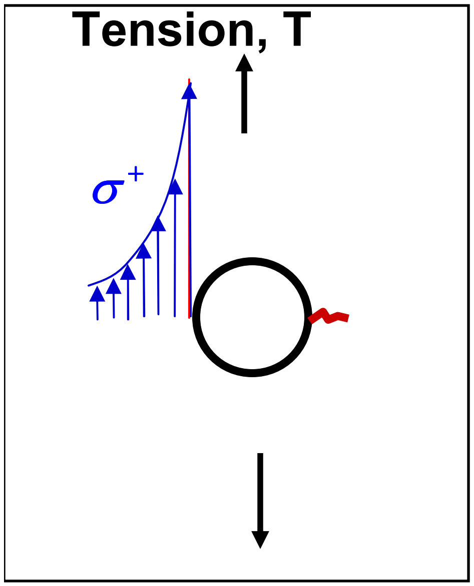
Profiling of plasma sprayed alumina-ceramic coatings on Ti (life enhancement)

NSLS X17B1

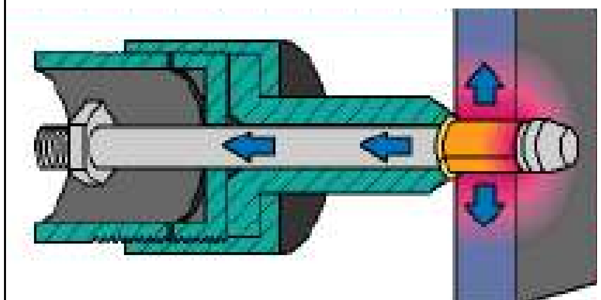


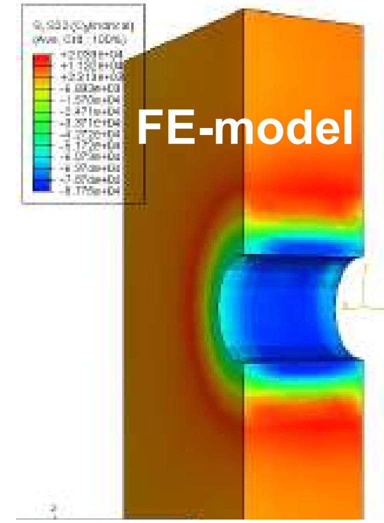

4-point bending
Ti
Al_2O_3
x_3
compression
tension
Ti-[110]
as-prepared
Ti
Substrate
$-\varepsilon_{33}$
$+\varepsilon_{11}$
x_3
coating
4-pt bending
Ti
Substrate
x_3
coating
Energy (keV)
alumina-coating
on Ti
NSLS X17B1
γ-Al_2O_3 (spinel)
[440]
Load response
study
composite layers
γ-Al_2O_3 (spinel)
[400]
nano-alumina-coating
γ-Al_2O_3 (spinel)
[440]
B.12
Bond- coat
Ti (hcp)-
substrate
x_3
[102]
Energy (keV)
[110]
[103]

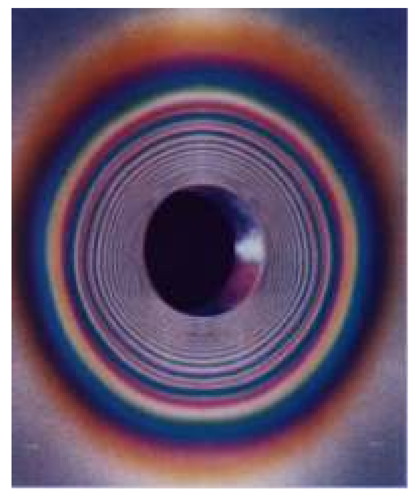
Rivet/bolt holes
- stress concentration
– fatigue failure



Split sleeve cold working (expansion)
- compressive stress







Photoelastic coating illustrates surface strain.

Aerospace applications

Excerpts from Proceedings
2007 Residual Stress Summit
& Internet

Split sleeve cold worked results EDXRD NSLS X17B1

$\varepsilon_{\theta\theta}$- crucial compression

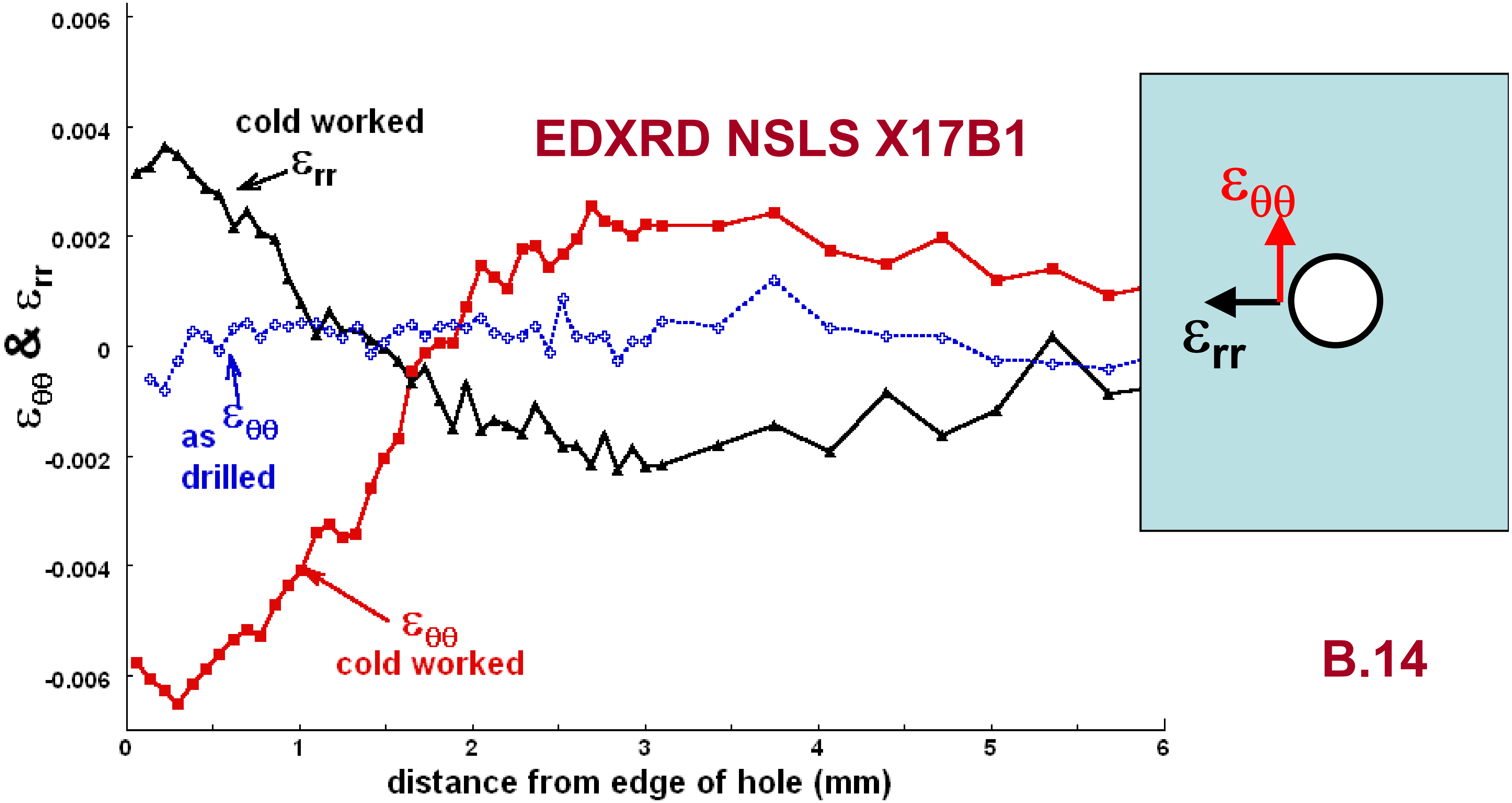
dramatic & long ranged

ε_{rr} – more complicated

Ti-alloy

Example*

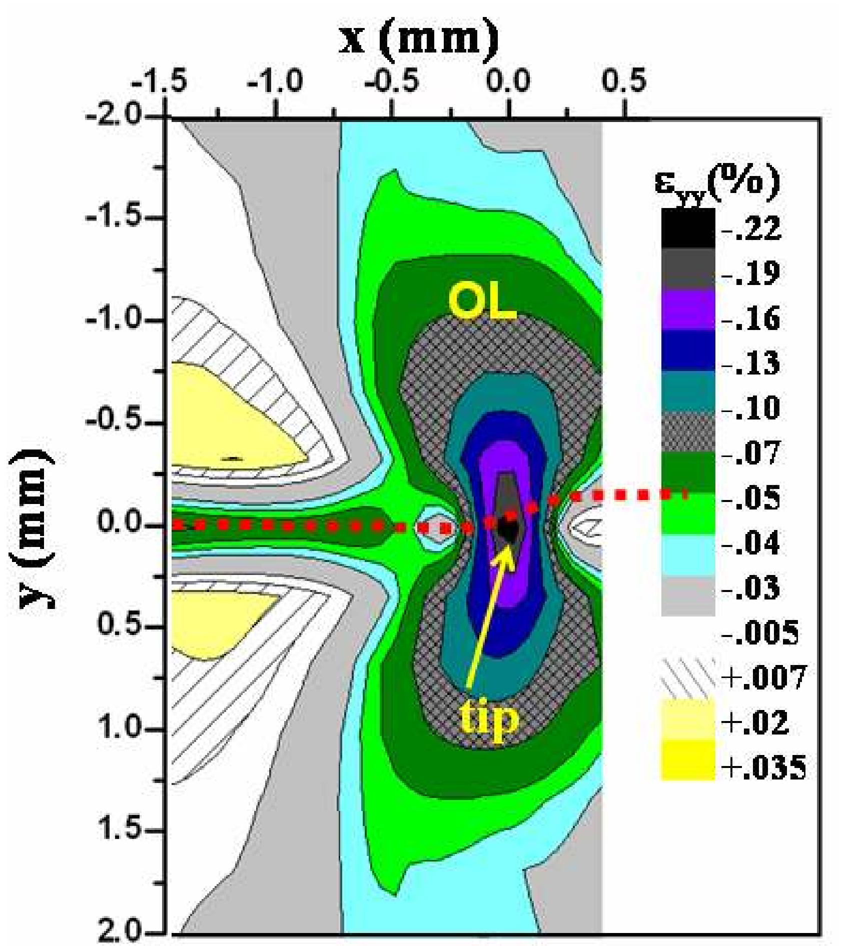
(*Representative of x-ray capabilities only not of optimized processing technique.)



B.14

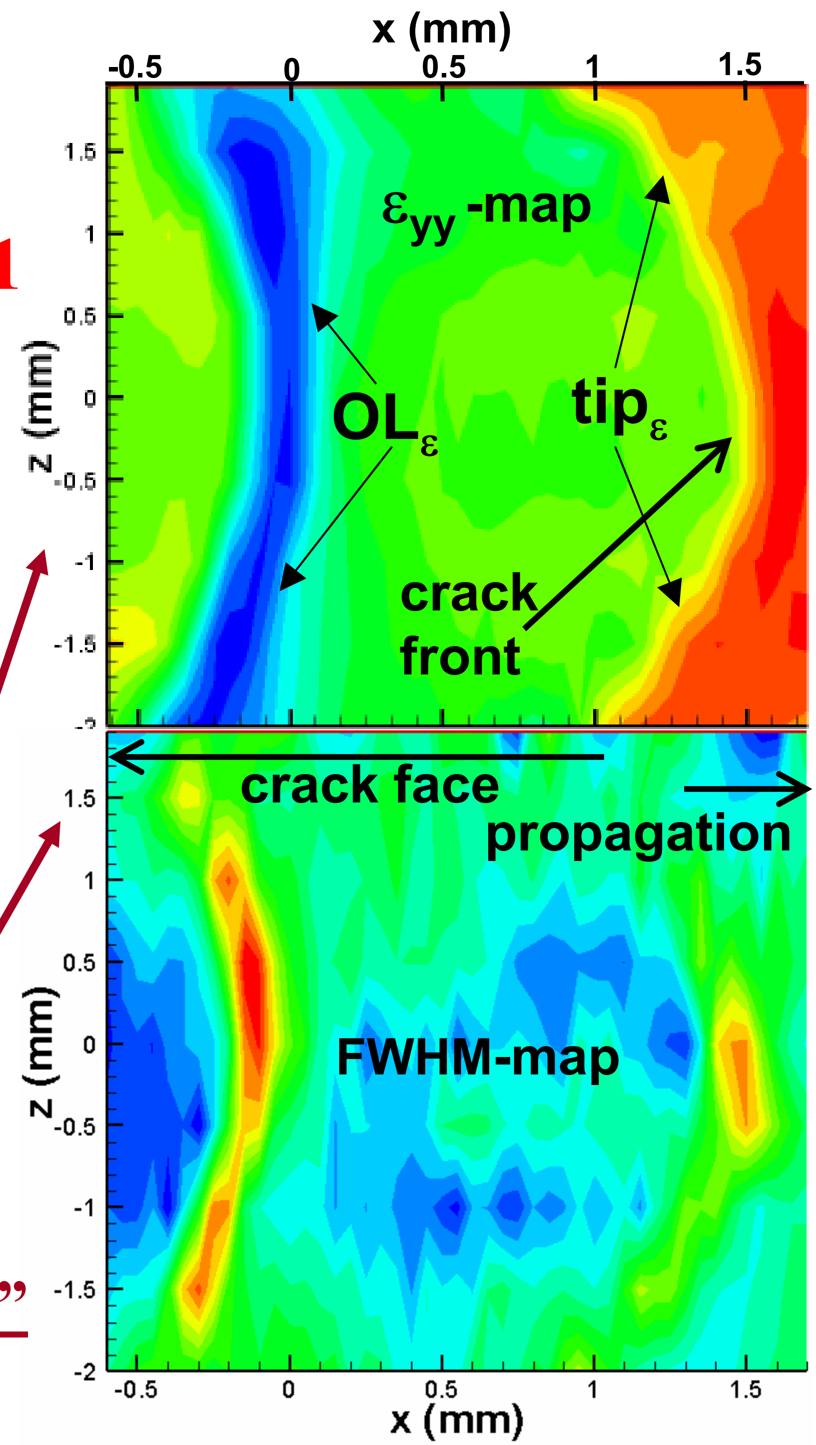
Fatigue Crack Strain Field Work

Crack Tip Strain Mapping



(immediately after overload, OL)

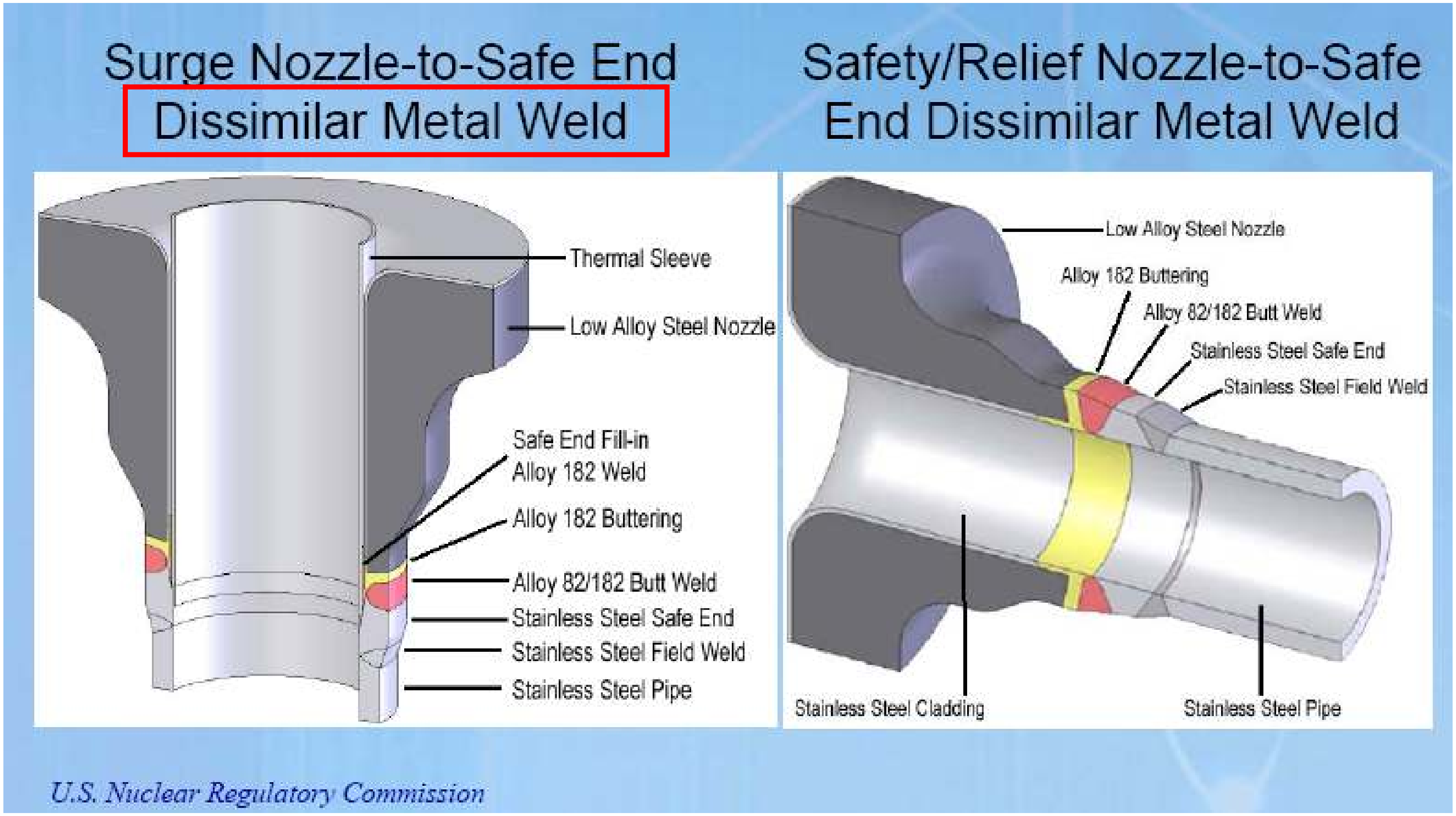
NSLS X17B1



Crack Front and OL “scar” Mapping/Imaging

B.15

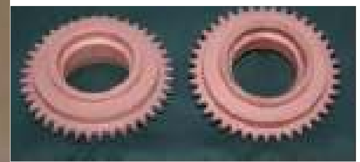
Welding applications example



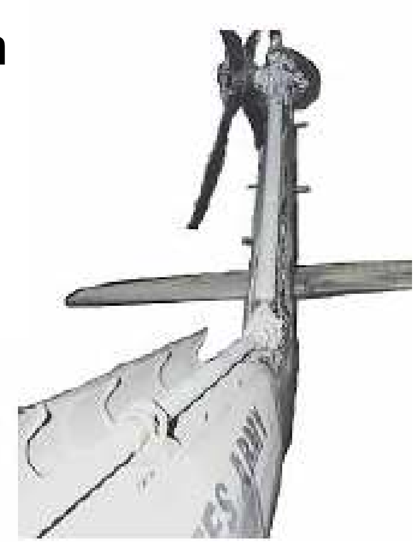
X-ray strain/phase mapping could be used to validate FE assumptions/calculations for crucial dissimilar metal weld studies or nuclear power applications

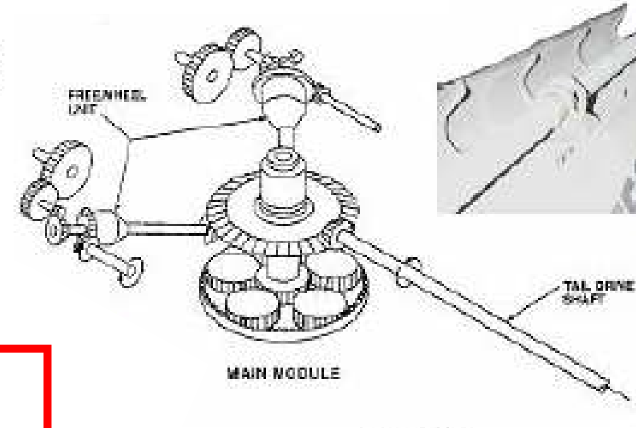
B.16

Gear fatigue cracking and compressive stress mitigation

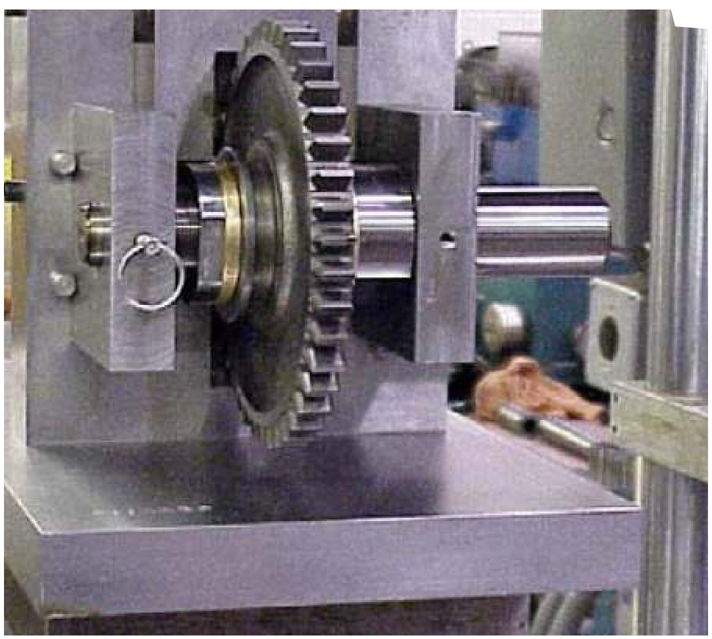


Test Gears:
- Single Tooth Bending
- Dynamic Testing





Amenable to in-situ x-ray studies



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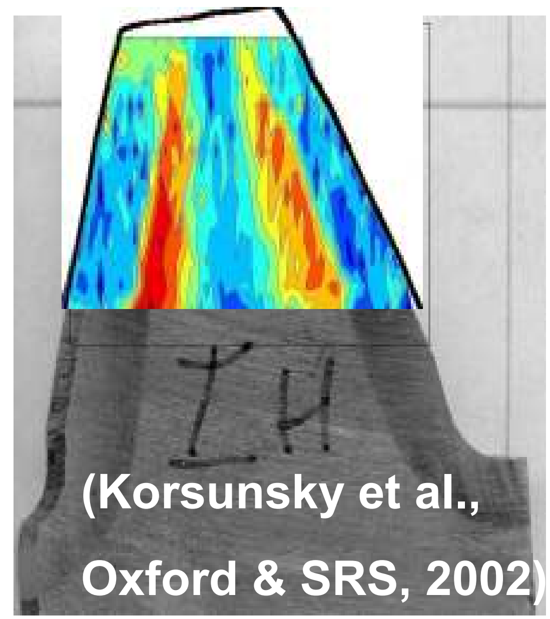
B.17



(Korsunsky et al., Oxford & SRS, 2002)

Some Capabilities/Concerns

Superconducting wiggler 30 – 200 keV
Multiple Hutches e.g. 5 - 3 simultaneous
white beam or monochromatic hutches (Side scattering monochromatic)

Last hutch (s) beyond confines of present building (e.g. Diamond JEEP materials line with hutch 11m X 7m)

In situ high capacity multi-axial loading frame + In situ high temperature

Magnetic field capacity

New software + software/inter computer interface.
Full integration between motor driving computer control and data collection control.
Real-time (during run, point by point) data processing
(currently only possible only after scan)
Data storage of sample positions with spectral data
Naming a chronology of data sets--- storage/retrevial capacities…

Laser scanners – digital image of specimen/component sample (e.g. SSCANSS) for rapid sample change, alignment and mapping.